The Discovery and Characterisation of Binary Central Stars of PNe

David Jones (djones@iac.es)
BINARY EVOLUTION

COMMON ENVELOPE
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drdjones.net/bCSPN for a full (regularly updated) list
• More than doubled the sample
• i-band survey of the Galactic bulge
• Close-binary fraction of ~20%
• Clear confirmation of a binary pathway for PN formation
Only 5 discovered by RV variability!

(plus one long-period system)
RVs are difficult!

- Need good spectral resolution
- Big telescope? Lots of time for “fishing”
- Nebular contamination is a problem
- On some level everything is variable!

... but very important!


An Interacting Binary System Powers Precessing Outflows of an Evolved Star

Boffin et al. (2012, Science, 338, 773)

- Some systems won’t be photometrically variable
  - Long periods
  - Double degenerates
• i-band (and Str y) quite effective (see OGLE)

• Some need narrowband (Hβ-continuum)

• Image subtraction very good but not “on-the-fly”
Recent efforts have focused on pre-selected "good" candidates:

- Filaments
- Knots
- Rings
- Jets
Very successful, but statistics are difficult

- Biased?
  - Spectral types
  - Period range
  - Age
  - ?

- Need for rigorous survey
  - 2 kpc volume-limited sample (Todd Hillwig, David Frew, myself)
  - Will be best measure of binary fraction to-date
Characterisation really needs RVs
(and eclipses and photoionisation modelling of host PN)
Only 8 systems properly constrained

But quite a few others have good estimates of (at least) the orbital inclination…

Jones et al. (2015, A&A, 580, 19) and references therein
Jones et al. (2014, APNVI)
Binaries definitely shape PNe

Orbital planes are \textit{ALWAYS} perpendicular to nebular symmetry axes
Inflated Secondaries!

<table>
<thead>
<tr>
<th>Nebula</th>
<th>Period (day)</th>
<th>$M_{CS}$ (M$_\odot$)</th>
<th>$R_{CS}$ (R$_\odot$)</th>
<th>$T_{CS}$ (kK)</th>
<th>$M_S$ (M$_\odot$)</th>
<th>$R_S$ (R$_\odot$)</th>
<th>$T_S$ (kK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abell 46</td>
<td>0.47</td>
<td>0.51±0.05</td>
<td>0.15±0.02</td>
<td>49.5±4.5</td>
<td>0.15±0.02</td>
<td>0.46±0.02</td>
<td>3.9±0.4</td>
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<tr>
<td>Abell 63</td>
<td>0.47</td>
<td>0.63±0.05</td>
<td>0.35±0.01</td>
<td>78±3</td>
<td>0.29±0.03</td>
<td>0.56±0.02</td>
<td>6.1±0.2</td>
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<tr>
<td>Abell 65</td>
<td>1.00</td>
<td>0.56±0.04</td>
<td>0.056±0.008</td>
<td>110±10</td>
<td>0.22±0.04</td>
<td>0.41±0.05</td>
<td>5.0±1.0</td>
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<tr>
<td>BE Uma</td>
<td>2.29</td>
<td>0.70±0.07</td>
<td>0.08±0.01</td>
<td>105±5</td>
<td>0.36±0.07</td>
<td>0.72±0.05</td>
<td>5.8±0.3</td>
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<tr>
<td>Ds 1</td>
<td>0.36</td>
<td>0.63±0.03</td>
<td>0.16±0.01</td>
<td>77±3</td>
<td>0.23±0.01</td>
<td>0.40±0.01</td>
<td>3.4±1</td>
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<tr>
<td>Hen 2-155</td>
<td>0.15</td>
<td>0.61±0.06</td>
<td>0.31±0.02</td>
<td>90±5</td>
<td>0.14±0.06</td>
<td>0.30±0.03</td>
<td>3.5±0.5</td>
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<tr>
<td>Hen 2-428</td>
<td>0.18</td>
<td>0.88±0.13</td>
<td>0.68±0.04</td>
<td>32.4±5.2</td>
<td>0.88±0.13</td>
<td>0.68±0.04</td>
<td>30.9±5.2</td>
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<tr>
<td>NGC 6026</td>
<td>0.53</td>
<td>0.57±0.05</td>
<td>1.06±0.05</td>
<td>38±3</td>
<td>0.57±0.05</td>
<td>0.05±0.01</td>
<td>146±15</td>
</tr>
</tbody>
</table>

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2 Double-degenerates (incl. best SN Ia candidate to-date)
6 Main sequence companions - all inflated w.r.t. ZAMS

Jones et al. (2015, A&A, 580, 19) and references therein
Evidence of Mass Transfer
Evidence of Mass Transfer

Carbon dwarf secondary

Miszalski, Boffin & Corradi (2013)
## Jets forming before CE

<table>
<thead>
<tr>
<th>PN</th>
<th>Neb. age (yrs)</th>
<th>Jet age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fg 1</td>
<td>2000</td>
<td>2500-7000</td>
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<tr>
<td>Necklace</td>
<td>1100</td>
<td>2400</td>
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<tr>
<td>ETHOS 1</td>
<td>900</td>
<td>1800</td>
</tr>
<tr>
<td>Abell 63</td>
<td>3500</td>
<td>5200</td>
</tr>
</tbody>
</table>

Jones (2014, APNVI)
Summary

• Discovery and characterisation of bCSPNe is a painstaking and time-consuming process
  • but worth doing!

• (Some) PNe are definitely shaped by binary stars

• bCSPNe are key to understanding close binary evolution (and other phenomena - see Romano’s talk)
  • Too many double-degenerates? (Too many short period binaries?)

• Pre-common-envelope mass transfer